MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

VOL. 58, No. 11
W. B. No. 1032

NOVEMBER, 1930

CLOSED JANUARY 3, 1931
ISSUED JANUARY 31, 1931

MEASUREMENTS OF VISIBILITY AT DANZIG

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I. *Theoretical introduction.*—In the following discussion there is involved throughout the sighting distance of a black object in the daytime. By sighting distance we understand the greatest distance from the observer at which the object is still discernible.

The visibility, and hence the sighting distance, of a black object by day depends on conditions entirely different from those governing the visibility of a source of light at night. While at night the source of light appears duller and duller the farther it recedes from the observer, by day the black object appears lighter and lighter, within certain limits, the farther it is removed from him. At night there results a loss of light, by day an increase in light, with increasing distance to the source of light or to the black surface.

That by day there actually results an increase in light with increasing distance of the black object from the observer is immediately perceivable when on a hazy day one follows with the eye a receding train. At first it appears dark on the light background of the horizon and then, with increasing distance, lighter and lighter until it becomes as light as the horizon and hence becomes invisible. Another example: If there lie behind one another several similarly forested hills, then—with weather sufficiently hazy—to the unaided eye the second hill appears lighter than the first, the third lighter than the second, and so on. One then sees a whole series of steps in brightness [1] (1).

This increase in brightness of a black object by day with increasing distance of the object from the observer comes about through the diffuse scattering of light by the air and the disturbing particles contained in it. Let us consider a space of the pyramid of visual rays determined by the eye and the object. Into this there falls light from the sun, the sky, and the earth's surface. The air molecules contained in this space scatter light from these light sources in all directions according to Rayleigh's law of diffraction, while the larger disturbing particles, such as water droplets, dust particles, etc., do this through reflection, refraction and bending. Thus naturally there is scattered from the space under consideration a certain stream of light in the direction of the observer.

This stream of light A can be readily calculated. Let r be the distance of a volume element from the observer (fig. 1), and ω the angle of aperture under which the object appears, then the size of the volume element is given by $\omega r^2 dr$. The light stream scattered from a portion of space is proportional to the size of the space $\omega r^2 dr$ and the number of particles contained therein or, what amounts to the same thing, the turbidity of the air contained in the space. This we characterized by the coefficient of diffraction a. Thus the amount of scattered radiation becomes $C.a.\omega r^2 dr$, where C depends in complex manner on the incoming streams of light.

But only a part of this amount reaches the eye of the observer. In the first place this scattered radiation spreads out on a spherical surface so that there enters the factor r^{-2}, and in the second place the diffuse radiation is diffracted on the path to the observer so that there enters the factor e^{-ar} where, as above, a is the coefficient of diffraction. Therefore from a volume element that is found at the distance r from the observer there reaches the eye of the observer a stream of light

$$d\phi = e^{-ar} r^{-2} Ca\omega r^2 dr = \omega Cae^{-ar} dr$$

From a pyramid of visual rays with a length of l there is, therefore, scattered to the eye the light stream.

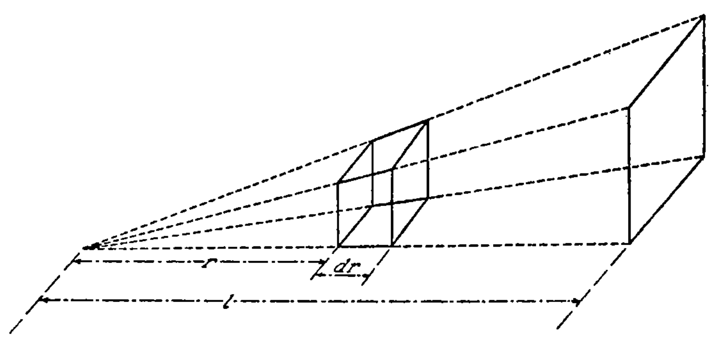

FIGURE 1.—Pyramid of visual rays

$$\phi = \omega \int_0^t aCe^{-ar} dr \tag{1}$$

The integration can be readily performed under the condition that a and C are independent of r. Hence all further consideration is limited to the following conditions

1. The direction of sight lies on the horizon and the turbidity of the air in the horizontal plane is constant.
2. The sky is cloudless, so that the same skylight prevails everywhere.
3. The surface of the earth is even and has everywhere the same albedo, so that the same *Unterlicht* prevails everywhere.

Then follows:

$$\frac{\phi}{\omega} = C\,(1 - e^{-al}) \tag{2}$$

wherein $\frac{\phi}{\omega}$ as the stream of light per unit angle has the dimension of a surface brightness. We call it briefly the air light (*Luftlicht*) of the pyramid of visual rays.

[1] In this connection F. Löhle (1) has devised a method of measuring the factor $1-e^{-al}$ appearing in Formula (4), and in his measurements at Potsdam has found good agreement between theory and observation.

If there stands at the distance l a black object with a surface brightness of 0 then $\frac{\phi}{\omega}$ produces an apparent surface brightness h_s of the black object, so that with $h_s = \frac{\phi}{\omega}$:

$$h_s = C\ (1 - e^{-al}) \tag{3}$$

The constant C is determined from the simple consideration that h_s merges into the horizontal brightness h_h when the object is removed to infinity; so that

$$h_s = h_h\ (1 - e^{-al}) \tag{4}$$

Hence h_s disappears for $l = 0$, as, indeed, must be.

We take the last relation (4) as the air light formula.

Under the above-mentioned assumptions and with the air light formula there can be calculated the sighting distance (B)(**3**) for black, white, or colored objects. In the following we limit ourselves to black surfaces.

The sighting distance s_s of a black surface by day is determined immediately in that $l = S_s$ when $\frac{h_s - h_h}{h_h} = \epsilon$, where ϵ is the minimum relative difference in brightness that the eye can discern. For our problem ϵ is sufficiently constant and has the value of 0.02. Then

$$S_s = \frac{1}{a} \cdot ln \frac{1}{\epsilon} \tag{5}$$

Since the azimuth does not enter into (5) it results that the horizontal sighting distance of a black surface before the horizon is independent of the sun's position and that it is just as great when from the observer's position the object stands below the sun as when it stands opposite the sun.

This statement of theory stands in full contradiction to the current conception, according to which the sighting distance is considerably less in the direction of the sun than in the direction removed from the sun: a conception that appeared supported by the results of measurements in several investigations.

It was necessary, therefore, to test the theory.

II. *Problem and arrangement of the measurements.*—The testing of the theory is best made with the aid of formula (4), which shows that the quotient (6) $q = \frac{h_s}{h_h}$ is independent of azimuth. This is readily tested when we place on a circle (l = a constant) a sufficient number of black objects and measure h_s and h_h at each azimuth. Naturally, instead of several fixed objects we can use one object moving in a circle. In choosing the place of observation consideration is to be given that the above-named prerequisites are sufficiently fulfilled. This necessity can not be pointed out too emphatically. So long as it is not a matter of statistical observations, but one of the basic clarification of the statement of a question in the problems of meteorology, the correct choice of the place and time of observations is just as essential as the correct choice of methods of observation.

In order that the assumptions of theory may here be considered as fulfilled, the following are necessary:

1. Measurement must be made only with cloudless sky, since then the skylight is everywhere the same.

2. When snow lies on the ground measurement must be made over surfaces that are similarly covered with snow, since only then is the *Unterlicht* everywhere the same.

3. In the vicinity of the sun the object and the horizon must join, since otherwise the pyramid of visual rays toward the object and that toward the horizon will be at unequal distances from the sun, and since in the vicinity of the sun the brightness of the sky increases more than 10 per cent for 1° of approach to the sun.

4. In the vicinity of the coast measurement over the sea must be made only with onshore winds, since only then does the pyramid of visual rays lie with certainty within one and the same body of air.

5. In the vicinity of a large city the measurement must be made only to the windward of the city and then only when the pyramid of visual rays extending to the sighting lies outside the region of the city.

In view of these considerations the peninsula of Hela, jutting far into the Baltic Sea, was originally chosen as the place of observation. Unfortunately it had to be abandoned for political reasons. Since everything was prepared for observations at sea the first measurements necessarily took place from the east mole (Danzig). See 4 and 5 above. In order that conditions might be satisfactory the place of observation was later transferred 11 kilometers toward the interior and south of Danzig to Rostau, whereby southerly winds and the influences of a large city and of the coast were sufficiently eliminated.

In the measurements over the sea from the east mole (Danzig) the telephotometer, the range finder, and the theodolite were set up on the point of the mole. As an object there served a sail or material half black and half white (Figure 2), of which only the black surface having a size of 6 by 6 meters was measured. The sail was towed on a dredging boat on semicircles of 2 and 4 kilometer radius around the mole, and the position of the object was determined from time to time with the theodolite and the range finder (3 meter base).

In the measurements on land at Rostau there were set up 16 objects 1.35 by 1.35 meters on a circle with a radius of 1 kilometer.

The albedo of the objects was somewhat less than ½ per cent; the light reflected by the black surface was first noticeable at very great sighting distances.

The measurement of the apparent brightness h_s of the black object and the brightness of the horizon h_h was made with a telescope of 195 centimeters focal distance and an astrophotometer for surface photometry, the Apho 4 by Rosenberg of the Askania Works, Berlin—Freidenau, placed at my disposal as a loan.

III. *Results of the measurements* (**4**), (**5**).—1. East mole (*Ostmole*). The results of measurements for one day are given in Figures 3 and 4. Each value entered rests here on only one reading. The abscissa is the azimuth A, the ordinates are h_h (upper curve o) and h_s (lower curve +). Here the brightnesses are not reduced to equal distance from observer to object. However, the departures are very small and here unimportant.

The measurements give the result, surprising at first sight, that the brightness of the black object, when this stands in its own shadow ($A = 0°$) amounts to several times (three to twelve times) the brightness under which the surface appears with full illumination ($A = 180°$). This result, which had not been expected, is explained very simply by the theory of vision in that the apparent brightness of the black surface comes about through the air light; the horizontal brightness is the air light of an endlessly long pyramid of visual rays, so that the two thus change homologously. This can be plainly recognized from Figures 3 and 4.

The change in brightness of the black surface in these experiments was especially striking in that in addition to the black surface, as shown in Figure 2, there was

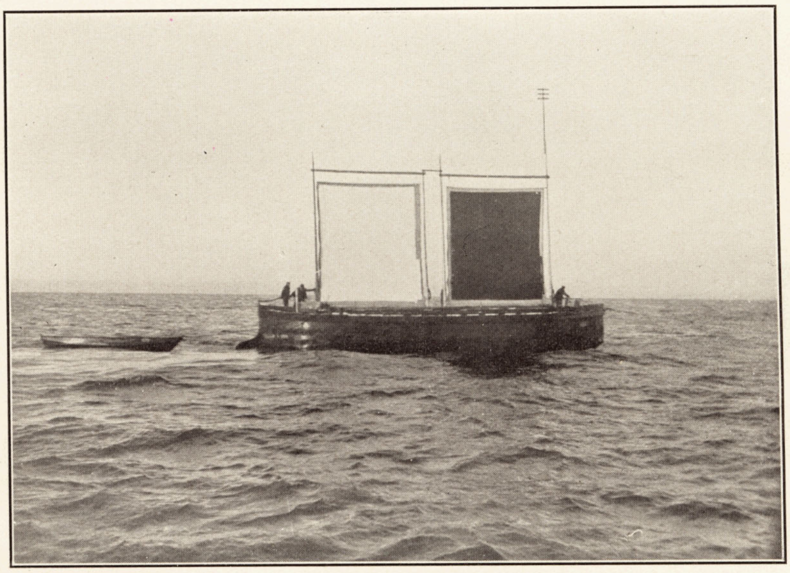

FIGURE 2.—Sighting objects on moving dredge boat

also carried along a white surface. The black and the white surfaces were noticeably equally bright and differed in no manner one from the other when the boat carrying the object stood under the sun as seen from the observer and was sufficiently distant from the observer. Thereby the object ship was always plainly contrasted with the horizon. On the other hand one surface appeared deep black and the other glaring white when both stood opposite the sun as seen from the observer. From this fact it is shown very beautifully that the matter of the changes of brightness of the black surface is no academic bagatelle.

The next problem is to investigate whether the apparent brightness of the black surface is exactly proportional to the horizon brightness; that is, whether q possesses the same value in all directions. For this the values belonging to h_s and h_h must be evaluated. This was done with the aid of the smoothed curves $\bar{h}_s$, $\bar{h}_h$ drawn in Figures 3 and 4 for $A=0°$, $10°$, $20°$ . . . $180°$. Then there were formed the values $\frac{\bar{h}_s}{\bar{h}_h}$ and these were reduced to the same distance by aid of the air-light formula.

The q values so formed are by no means constant, as theory requires. They show, rather, both a time as well as an azimuthal dependence.

The time dependence of q is here (see fig. 5) very plainly decided. Both in the azimuths around 180° and in the azimuth 0° there results a plain decrease of q with change in time. The same holds for other azimuths. The q values at 180° and 0° lie nearly in a straight line. One can therefore look upon the line passing through the four points as the time change of q.

Just as plainly decided is the azimuthal dependence of q. In figure 6 the courses of the object are drawn as arcs with radii of 2 and 4 kilometers. The arrows give the direction of travel. In addition there is drawn q as radius vector out from the east mole, as is carried out for $A=0°$ and $A=180°$, and in the same direction which the pyramid of visual rays had at the moment of observation. In general, only the end of the vector is entered; its length for the azimuths, 0°, 10°, 20°, . . . 180° is marked by a circle or a double circle. The azimuths 0° and 180° show the highest values, those from 50° to 110° plainly the lowest values. The explanation of this azimuthal departure follows from the course of the object and the wind direction; offshore south-southeast winds on this day brought turbid air masses from land to sea. Through the deficiency in disturbing particles at sea the turbidity decreased more and more in the seaward direction. The least mean turbidity is thus to be expected in those pyramids of visual rays which lie at right angles to the coast, while the greatest mean turbidity may be expected in those pyramids of visual rays that lie parallel to the coast. In both cases there is agreement with observation.

In both semicircles this state of conditions is found very plainly, and since the air current on this day came unchangingly from the south-southeast, so in the double occurrence of azimuthal changes there can be seen a strong proof of the correctness of this conception. The azimuthal changes are thus explained by the assumption that with offshore wind the turbidity decreases seaward.

Summary of the results: The measurements at the east mole have brought the information that the brightness of the black surface changes identically with the brightness of the horizon and that below the sun it amounts to many times the brightness that is measured opposite the sun, and that the black surface at a proper distance from the observer and below the sun can be just as bright as a white surface with high albedo (70 per cent).

In addition the measurements show that with offshore winds over the sea and in the lee of a large city the air is not optically homogeneous.

(2) *Rostau, winter, circles.*—In order to avoid the influences of coast and a large city, as was mentioned, the place of observation was later removed toward the interior, to Rostau, 11 kilometers south of Danzig. In these measurements every emphasis was placed on the exact comprehension of the value q.

In all there were obtained 88 values of q which rest on 4 to 13, generally 5 to 7, photometric *focusings* over three complete circles and two semicircles on three days. The values are represented collectively in figure 7, as follows: For each semicircle, in one case after picking out a linear time course, there was formed a mean value q^m and then $q(A)/q^m$. The value qA/q^m was represented in polar coordinates with the azimuth A as amplitude and $q(A)/q$ as length. There was entered only the end of the vector, whose position is determined by the middle point of the small circle.

If the theory were entirely fulfilled all of the small circles would have to be placed on the large unit circle. As is seen this is very nearly the case. However, there remains a relatively large scattering. As a measure of the scattering we use, as ordinarily, the deviation

$$\Delta = \frac{q(A) - q^m}{q_m} \cdot 100$$

As a detailed investigation shows, the deviations can be looked upon as accidental; it is therefore admissible to combine the values into mean values. Then there results for the individual azimuth groups the following mean deviations:

TABLE 1.—*Rostau, January-February, 1929. Number of observations, 86*

	Azimuth					
	0°–10°	10°–30°	30°–50°	50°–110°	130°–170°	170°–180°
Observations	19	12	10	19	13	13
Mean deviation Δ, per cent	−1.5	−4.4	−2.8	−0.3	+6.3	+2.5
Mean error	±1.0	±3.0	±2.6	±1.9	±2.5	±1.6

The deviations are thus very small and exceed only in an unimportant way the mean error.

Summary of results: Despite the low elevation of the sun (<19°) and the high relative humidity ($f=60$ . . . 90 per cent) the mean deviations do not exceed 6 per cent. The difference $\Delta(180)-\Delta(0)$ amounts to only (4.0 ± 1.9) per cent.

In the winter measurements at Rostau we can, therefore, discover a good confirmation of the theory, at least for the short sighting distances occurring with these winter measurements. The result has so much the heavier weight since the elevations of the sun were small so that a plain difference would necessarily have appeared between q (180) and q (0) if such had generally been present.

3. *Rostau, summer, circles.*—The measurements were carried out in the summer of 1929 without important changes by my pupil, H. Rühle, at Rostau. In all 233 values were measured; these rest on nine readings on seven days.

The results are represented in Figure 8 in the same manner as for the winter measurements. There is noted again the large scattering. If we combine the values

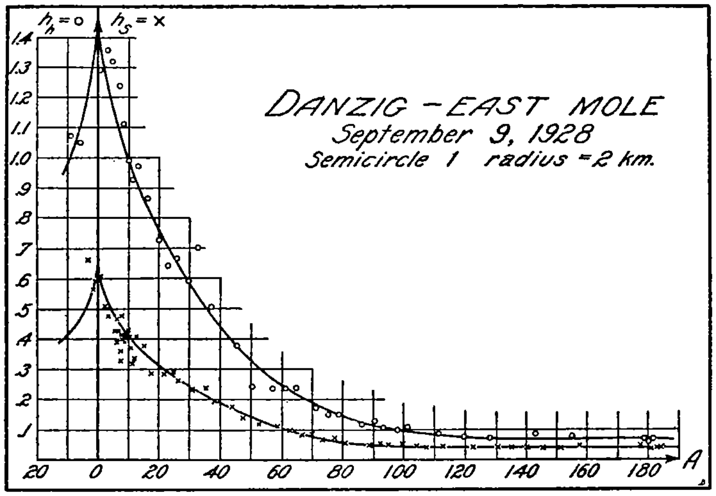

FIGURE 3.—September 9, 1928 (Danzig) east mole, semicircle 1 radius=2 kilometers

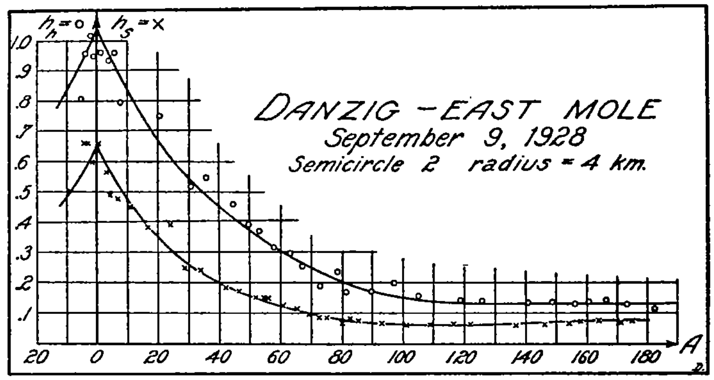

FIGURE 4.—September 9, 1928 (Danzig) east mole, semicircle 2 radius=4 kilometers

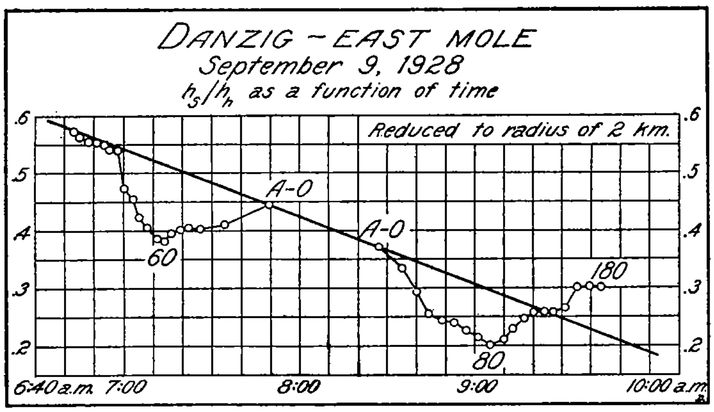

FIGURE 5.—September 9, 1928 (Danzig), east mole, h_s/h_h as a function of time reduced to radius of 2 kilometers

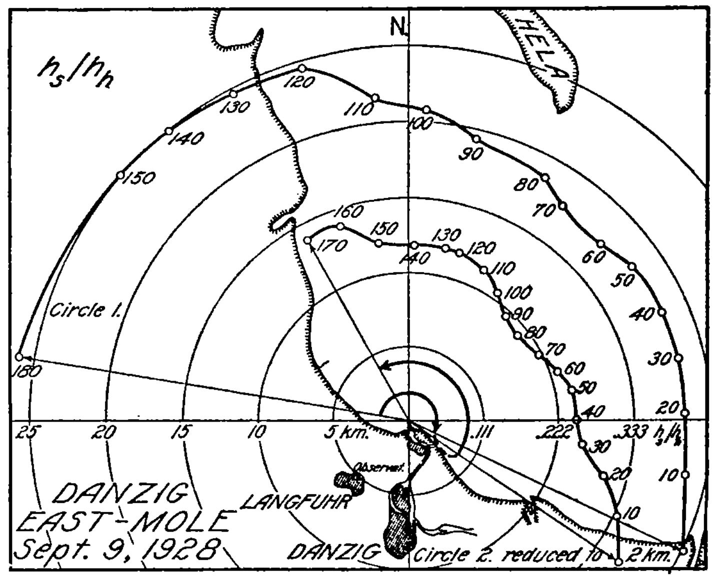

FIGURE 6.—September 9, 1928 (Danzig), east mole, Circle 1 and Circle 2 reduced to 2 kilometers

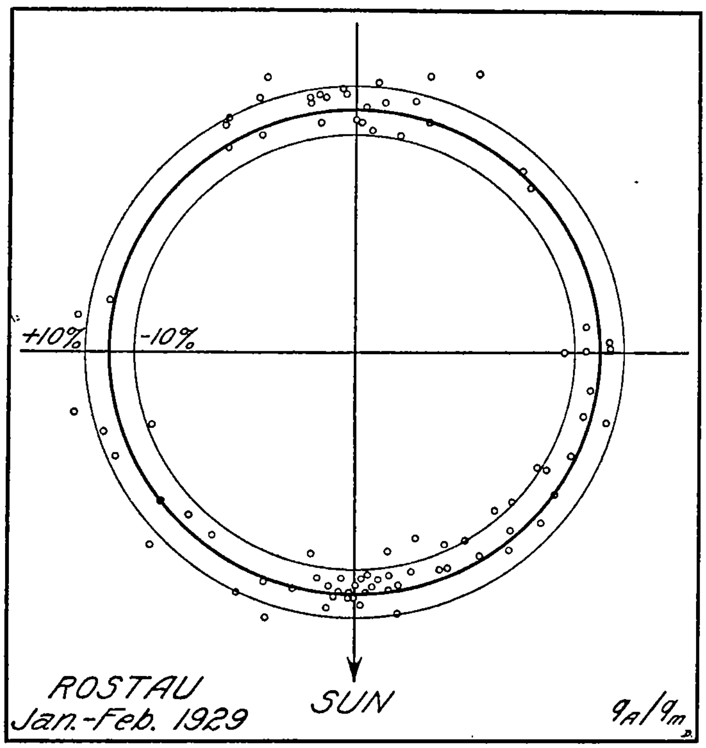

FIGURE 7.—Rostau, January-February, 1929, q^A/q_m

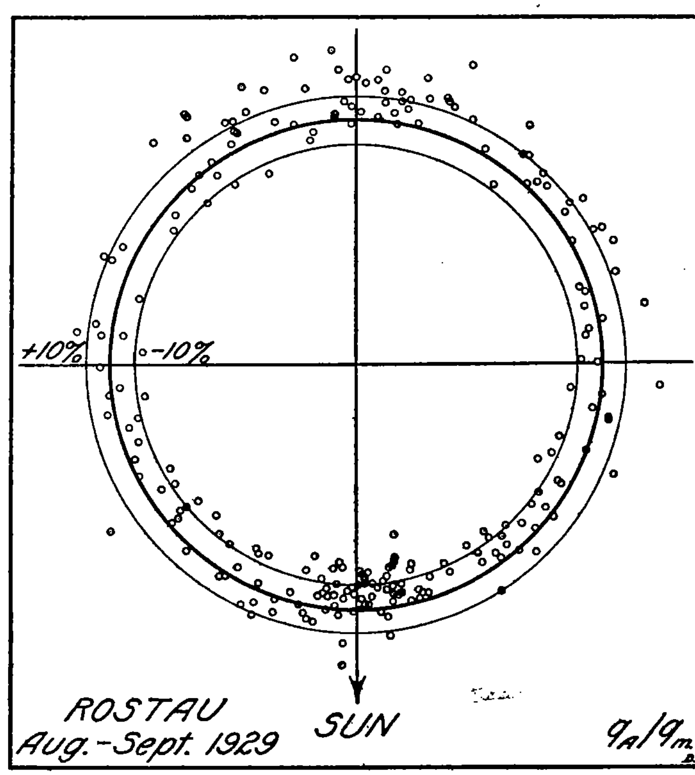

FIGURE 8.—Rostau, August-September, 1929, q^A/q_m—S_s/S_m

into means according to azimuth groups there are obtained the following values:

$$\Delta=\frac{q(A)-q_m}{q_m}\cdot 100$$

in dependence on the azimuth A.

TABLE 2.—*Rostau, summer of 1929. Number of observations, 233*

	Azimuth						
	0°-10°	10°-30°	30°-60°	60°-90°	90°-120°	120°-150°	150°-180°
Observations	51	32	34	24	24	24	44
Mean deviation Δ, per cent	−5.0	−5.8	−4.5	−2.4	+3.0	+5.0	+9.7
Mean error	±1.2	±1.6	±1.3	±1.9	±1.8	±2.2	±1.4

Here there appears very plainly a dependence of the deviation on the azimuth A of the object in relation to the sun. The difference Δ (180) − Δ (0) amounts to (14.7 ± 1.8) per cent and thus lies outside the limit of error. The cause of this finding, plainly departing from the winter conditions, evidently lies in the fact that the surfaces are not entirely black; the albedo does not have the value of zero. If the albedo amounts to only a few thousandths, then with sufficient *illumination* by the sun, especially with sufficiently low turbidity, it becomes noticeable throughout. The fact that the light reflected by the black surfaces increases with the intensity of illumination needs no discussion. The fact that with decreasing turbidity it has greater and greater importance has a two-fold reason: In the first place with low turbidity the air light is very small, so that the true surface brightness becomes decided relative to the apparent brightness, and in the second place the reflected light is diminished very little on the path from the object to the observer. The two influences combine, so that with decreasing turbidity (or increasing sighting distance) the influence of the albedo increases rapidly.

With this there agrees in the best manner possible the fact that on the days of measurement the sighting distance lay between 4 and 12 kilometers in winter and between 16 and 44 kilometers in summer, so that the influence of the albedo came into effect not in winter but, indeed, in summer. With this view there agrees further the sign of the deviation: Opposite the sun, where the surface is fully illuminated by the sun its true surface brightness is greater than below the sun where the surface stands in its own shadow. On the other hand the sign of the deviation is not consistent with the current idea that the sighting distance is greater opposite the sun than below the sun since then Δ (180 < 0, Δ(0) > 0 must be reversed.

Under reasonable assumptions the influence of the albedo, (inclusive of scattered light) can be calculated approximately and H. Rühle finds that the observed variation Δ (180) − Δ(0) is of the same order as the calculated variation and decreases rapidly with increase in q, so that for $q=0.08$ the variation relative to the calculations amounts to 20.8 per cent, while for $q=0.226$ to only 6.3 per cent.

Summary of the results: The repetition of circle measurements in summer at great distances shows a plain dependence of the deviation Δ on the azimuth of the sun A. It probably comes about that this azimuthal difference of Δ is a result of the reflective power, although small, of the black surface, since with great distances the air light decreases to the order of the reflected light.

4. *Rostau, auxiliary points.*—In order to strictly remove in a single case the influence of the albedo and of the scattered light, H. Rühle carried out four series of measurements.

In the azimuth and under the elevation of the fixed object as seen from the observer, there were set up auxiliary objects of the same low albedo, but at a lesser distance than the object—in furtherance of a method that F. Löhle had already proposed. The size of the auxiliary objects was so chosen that from the observer they appeared under the same angle as did the fixed object at a distance of 1,000 meters; thus in both cases the scattered light was the same in amount.

If h'_{s2}, h'_{s1}, and h'_h designate the brightnesses as read on the photometer for the object, the auxiliary object, and the horizon in the same azimuth; σ, the scattered light; and ζ the true surface brightness of the black surface (the reflected light); then there exist the following relations:

$$h'_{s1}=h_h\cdot q_1+\sigma+\zeta\cdot e^{-al_1}$$
$$h'_{s2}=h_h\cdot q_2+\sigma+\zeta\cdot e^{-al_2}$$
$$h'_h=h_h\qquad+\sigma$$

From these equations σ and ζ can be eliminated (this is the purpose of the measurement arrangement!) and there follows:

$$a=\frac{1}{l_2-l_1}\cdot ln\left(1+\frac{h^1_{s2}-h^1_{s1}}{h^1_h-h^1_{s2}}\right)$$

These measurements then furnished the following values of $\frac{a_{180}-a_0}{a_m}$. In the following table n indicates the number of individual a values, each of which rests on 13 photometric focusings, and s_s, the sighting distance calculated from the observed value of a.

TABLE 3.—*Rostau, southeast to southwest winds, cloudless sky*

Sighting distance in kilometers, s_s	Number of observations, n	$\frac{a_{180}-a_0}{a_m}$ (per cent)
33-17	32	+(10.2±2.4)
12	17	+(8.9±4.6)
8-13	10	+(5.3±4.3)
9-10	7	+(3.7±3.9)
3-5	23	+(2.2±2.9)

From this it is seen that with short sighting distances the deviations lie within the rather small limits of error. With great sighting distances the deviation plainly exceeds the limits of error. This result cannot be explained with the current conception that the sighting distance is greater opposite the sun than below the sun, since then the sign of the variation would have to be negative. The reason for this variation can be sought, then, only in nonhomogeneity of the air, which comes about in that with these great sighting distances the pyramid of visual rays is projected into the urban section of Danzig. That this explanation is correct proceeds from the fact that on a day with wind from the sea the sign was reversed for very great sighting distances.

TABLE 4.—*Rostau, northeast wind, cloudless sky*

Sighting distance in kilometers, s_s	Number of observations, n	$\frac{a_{180}-a_0}{a_m}$ (per cent)
>50	15	−(6.3±4.7)

On this day the decided northeast wind brought clean sea air into the measuring space on land. With advance over the land the sea air most certainly came to contain more disturbing dust, so that the turbidity increased inland toward the southwest, while seaward, to the northeast, there was decrease. (A second example of this in-

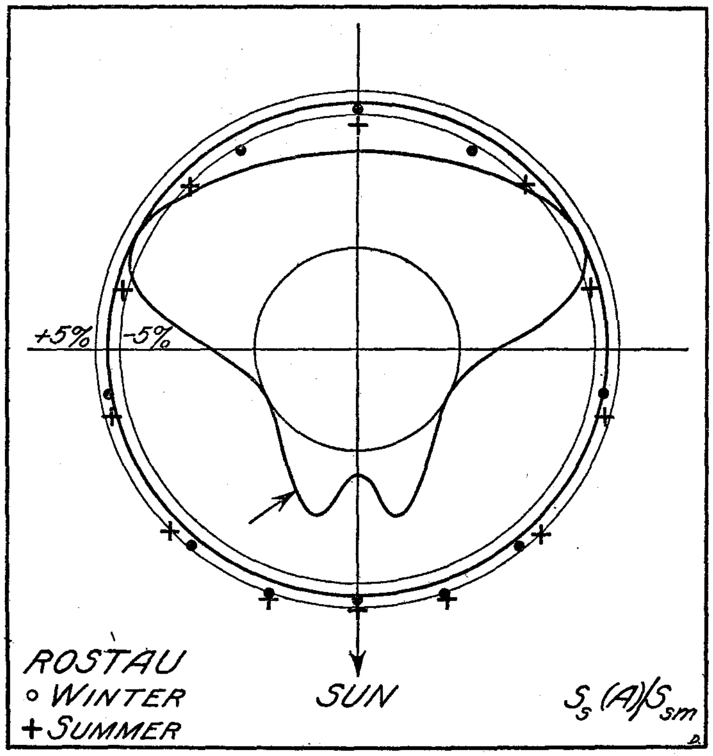

FIGURE 9.—Rostau winter and summer.

fluence of the northeast wind is furnished by a disturbed day.) In the five cases above named the turbidity on the contrary, plainly increased northward toward the city.

We may then state the matter thus: According to measurements in an atmosphere that is horizontally homogeneous the relation $q=\frac{h_s}{h_h}$ is independent of the azimuth of the direction of sight relative to the sun's vertical.

IV. *The sighting distances.*—In conclusion let us reckon the mean values of $\triangle(A)$ in relative sighting distances $\frac{s_s(A)}{s_{sm}}$ according to Tables 1 and 2 and plot the results in polar coordinates as earlier with those of $\frac{q(A)}{q_m}$

We then obtain Figure 9. In this there are entered for comparison the results obtained by another investigation, namely, the curve indicated by the arrowhead. It is perceived at first sight how slight are the deviations from theory now found in our Danzig measurements, even though in the values here used the influence of reflected light is not eliminated. The fact that the Danzig results so nearly approach theory has its basis first of all in the careful selection of the place of observation, one where nonhomogeneities of the air were especially avoided in the use of a strongly defined object, and in the application of the photometric process.

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METEOROLOGICAL CONDITIONS ON THE SANTIAGO (CHILE)-BUENOS AIRES (ARGENTINA) AIRWAY

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[Translated from manuscript in French by W. W. Reed]

The increasing movement of international aerial traffic between the capitals of Chile and Argentina by airpost and passenger companies has made evident the importance of meteorological studies of the regions crossed by aviators in their transcontinental flights over South America.

To give greater clearness to our study we divide the route from Santiago to Buenos Aires into three well-defined sections: The central region of Chile, the Andean region, and the central region of Argentina; and shall endeavor to summarize their meteorological conditions separately.

CENTRAL CHILE

The meteorological characteristics of this section vary with the seasons.

In summer, stability and continuity of atmospheric conditions predominate. The region of the central valley of Chile is warmed by the rays of the sun, and the temperature rises to 86° F., or higher, in the shade, consequently the air undergoes expansion and the pressure is lowered.

This decrease in pressure brings about a difference in pressure relative to the ocean and causes a southwest wind, generally called "travesia, or cross-wind," which blows with greater force in the transverse valleys of the watercourses. The régime of this wind is simple: it begins near midday, acquires its maximum force between 2 p. m. and 4 p. m., and falls away toward sunset. During the night and the morning there is calm or the wind blows in light breezes from north or northwest.

The "travesia" is a surface wind. Aerological soundings show that its maximum intensity is observed to a height of 500 meters; toward 1,500 meters it falls away and there is a belt with variable wind or calm; then at about 2,000 meters and up to 3,000 meters, according to the season, there are found constant northwest winds. During the summer, cloudiness is a minimum in the interior of central Chile, and visibility is good; however, there generally forms along the coast a stretch of fog, 30 to 40 kilometers wide, and also stratus cloud, both of which dissipate toward noon.

In winter the meteorological conditions in central Chile change completely. The atmospheric régime is characterized by instability; scarcely does the anticyclonic régime set in with fine, cold weather and south wind when there appears a cyclonic régime with unsettled weather, north wind, and rain. These changes may be studied on our daily meteorological charts.